

INFLUENCE OF BODY INTRUSION AND DECELERATION ON OCCUPANT INJURIES IN FRONTAL COLLISIONS BETWEEN PASSENGER CARS

**Tomiji Sugimoto
Hideki Suzuki
Honda R&D Co. Ltd. Japan
Yoshiji Kadotani
American Honda Motor Co., Inc. U.S.A.
Paper Number 433**

ABSTRACT

In this paper, the results from a matrix of tests performed to evaluate the response of the occupant injuries in collisions between passenger cars at 55 km/h are reviewed. Various crash tests were conducted with different vehicle weights and stiffness to investigate the effect of body intrusion and vehicle deceleration on occupant injuries.

Some cases showed high intrusion which resulted in high occupant injury. Conversely some cases exhibited severe body deceleration which resulted in high occupant injury. In the cases with severe body deceleration, the body intrusion was almost the same as a 64 km/h ODB test but the injuries occur because the body deceleration is much greater in the car-to-car collision than the ODB test.

To assess vehicle compatibility, an MDB test method is proposed which is one of the representative test methods of real world car-to-car accidents.

BACKGROUND

Research is continuing in countries around the world to improve vehicle compatibility, but the current situation is that concrete analysis and evaluation methods have not yet been clarified.

Research on compatibility begins with understanding the problems of compatibility, which is done through analysis of accident surveys. Of course, traffic environments differ according to the country, due to differences in the mass ratio and model configuration between the crash vehicles, and also the traffic environment and driver characteristics. These differences in environment and other factors are thought to result in different crash directions and speeds. At the same time, the progress of existing safety standards concerned with crash safety also differs between countries. This difference in safety performance between environments is one reason for the increasing complexity of this problem. That is to say, analysis of vehicle compatibility also faces the issues concerned with the establishment of a global standard.

INTRODUCTION

The authors are also involved in this research, and reported the results of comparative analysis of offset crash test methods at the previous '98 ESV. The offset deformable barrier (ODB) test method approximates only car-to-car crashes between vehicles of the same limited weight. However, the honeycomb bottoming out phenomenon, which does not occur in actual car-to-car crashes, sometimes occurred when the weight or stiffness of the test vehicle exceeded certain values.

The moving deformable barrier (MDB) test method which is being studied by the National Highway Traffic Safety Administration (NHTSA) has the problems of MDB over-ride onto the test vehicle, and also the honeycomb bottoming out phenomenon such as in ODB tests.

This paper added the perspective of occupant injury which was not touched upon in the previous comparative analysis of offset crash test methods. It also investigated the relationship between body deformation, deceleration and occupant injury severity. Methods for evaluating and testing compatibility are also discussed.

In particular, car-to-car tests crash were conducted with vehicles of different weights, and these results were used to verify changes in occupant injury severity and investigate characteristic factors which may be able to be used for compatibility evaluations.

In addition, it was found that the newly proposed evaluation method may be able to reproduce the body deformation and deceleration observed in actual car-to-car crashes by adjusting the honeycomb characteristics to prevent the above-mentioned MDB over-ride phenomenon.

Table 1 lists the features of current safety standards from the perspective of compatibility.

Table 1.
Features of Compatibility Evaluation Methods

Test Procedure		Car to Car	MDB	Full Lap	ODB
Crash Pulse		<i>stiff</i>	<i>stiff</i>	<i>stiff</i>	<i>soft</i>
Intrusion		<i>high</i>	<i>high</i>	<i>low</i>	<i>high</i>
Compatibility Factors	Mass	<i>base</i>	○	×	×
	Stiffness	<i>base</i>	△	△	△
	Geometry	<i>base</i>	△	△	△

○ can evaluate
× can not evaluate
△ difficult to evaluate

Load cell barrier is required to evaluate stiffness and geometry.

Frontal full lap crashes generate strong body deceleration, and these tests are considered suitable for improving the performance of restraint devices such as seatbelts and airbags. On the other hand, the ODB crash tests that are currently widely used could be said to focus on the evaluation of cabin integrity with respect to uneven input to the body. Also, it should be noted that the crash conditions are between vehicles of the same weight and model.

These crash tests are improving vehicle safety performance for the crash formats concerned. In other words, it can be said that the self-protection performance of vehicles is increasing. However, there is room for doubt as to whether improving the self-protection performance of each vehicle will clearly contribute to improving compatibility.

The usual method for improving compatibility is to improve factors that are thought to cause incompatibility. In other words, steps are taken to optimize each of the three factors which are generally related to incompatibility, namely: (1) Mass, (2) Stiffness and (3) Geometry. However, there is currently a lack of methods and criteria for evaluating these factors. Methods for simultaneously optimizing multiple factors have not been established.

This research performed a number of tests using vehicles of varying mass ratios in order to:

- 1) Clarify the position of current evaluation criteria.
- 2) Discover characteristic relationships between body deformation, deceleration and occupant injury severity.
- 3) Investigate the possibility of resolving issues concerned with improvement technologies.
- 4) Propose new evaluation methods.

TEST RESULTS

The test vehicles used were commercially available 1996 to 2000 year model passenger cars. The test conditions were a frontal offset of 50% with reference to the width of the lighter vehicle, and the two crash speeds of 50 km/h and 55 km/h for both vehicles. In addition, the tests were conducted with a colinear crash

angle so that the center axes of the vehicles were parallel. This test method is the same as that described in the authors' previous paper. The dummies used were HY-III dummies, and the test vehicles were equipped with airbags.

Fig. 1 shows the test matrix for the vehicles tested.

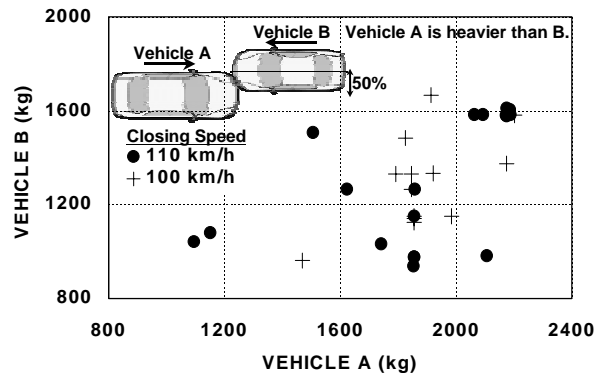


Figure 1. Weight Distribution of Test Vehicles.

Figs. 2 to 7 show the dummy injury severity measurement values for the driver. Reference value is a ratio of one to average injury number.

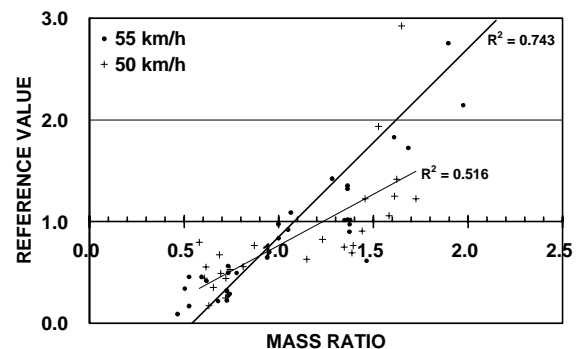


Figure 2. Relationship between Driver HIC and Mass Ratio.

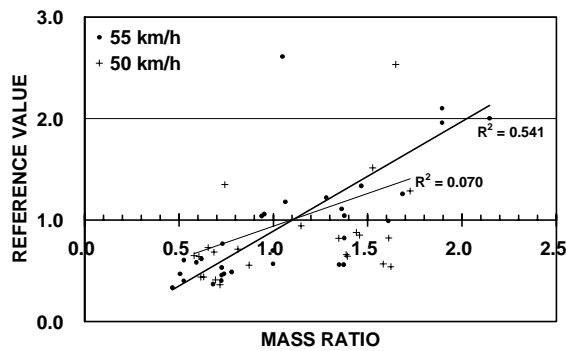


Figure 3. Relationship between Driver Nij and Mass Ratio.

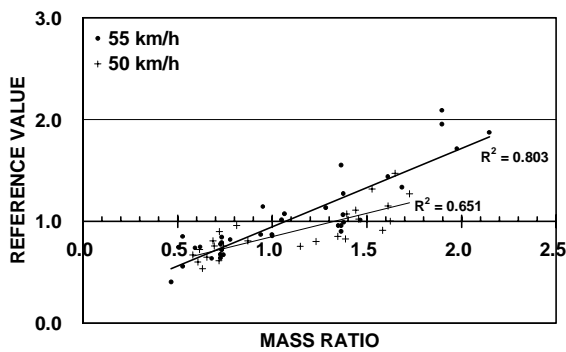


Figure 4. Relationship between Driver Chest G and Mass Ratio.

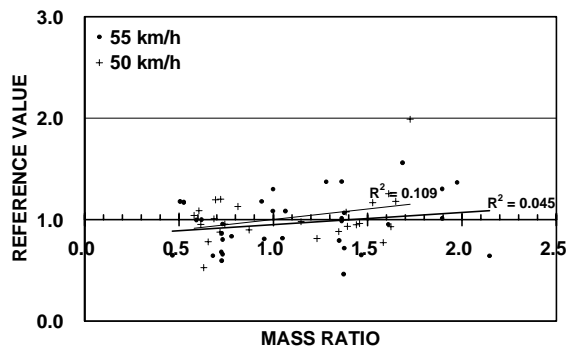


Figure 5. Relationship between Driver Chest Disp. and Mass Ratio.

The head injury (HIC), neck injury (Nij), Chest (G, displacement), femur load and tibia index (T.I.) characteristics from the perspective of mass ratio are as follows.

- HIC exhibited a large slope and also a high correlation relative to mass ratio. When the mass ratio exceeded 1:1.1, it exceeded reference value in some cases.
- Nij showed similar characteristics to HIC.
- Although Chest G showed strong correlation, it exceeded reference value even at mass ratios near 1:1 in some cases.

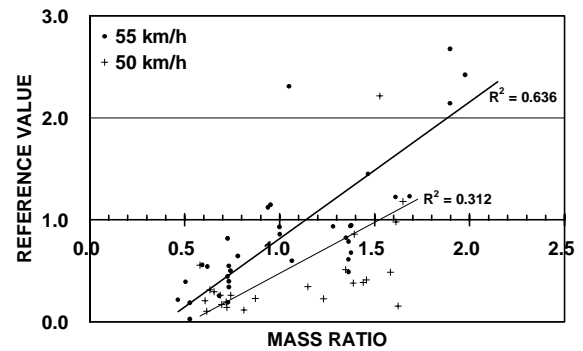


Figure 6. Relationship between Driver Femur Load and Mass Ratio.

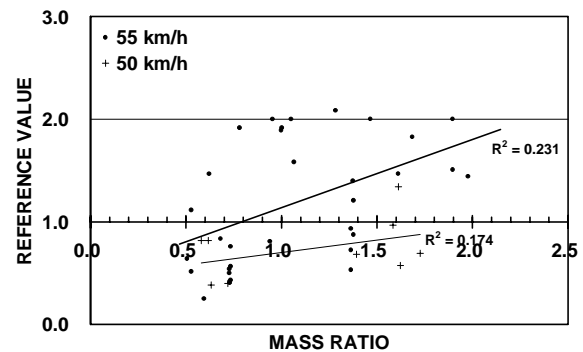


Figure 7. Relationship between Driver Tibia Index and Mass Ratio.

• Chest displacement did not show good correlation relative to mass ratio.

• Femur load exhibited correlation relative to mass ratio, and showed high value only when the vehicle experienced significant deformation. On the other hand, tibia index (T.I.) exceeded reference value in many cases for all mass ratios.

Figs. 8 to 11 show the average body deceleration, the maximum speed difference (delta V) and dummy injury severity.

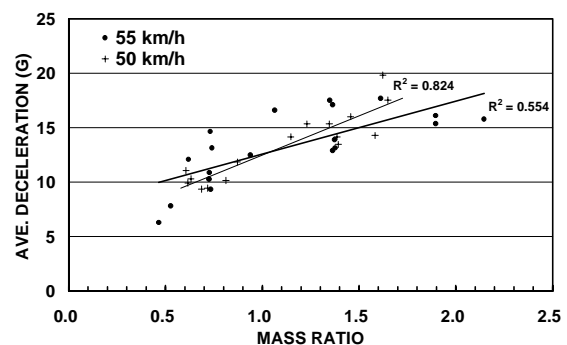


Figure 8. Relationship between Body Deceleration and Mass Ratio.

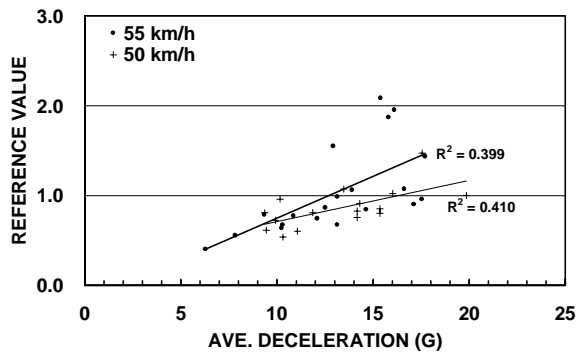


Figure 9. Relationship between Body Deceleration and Occupant Injury Severity (Driver Chest G).

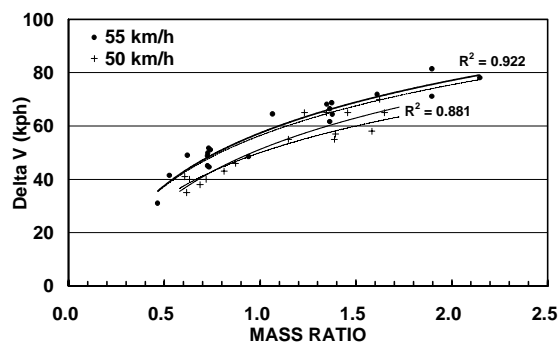


Figure 10. Relationship between Delta V and Mass Ratio.

Dotted lines are theoretical delta V curves of 50 and 55 km/h.

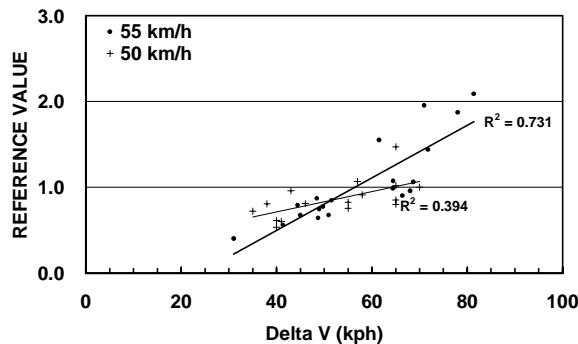


Figure 11. Relationship between Delta V and Occupant Injury Severity (Driver Chest G).

The average body deceleration was observed to increase as the mass ratio became larger, and Chest G was found to worsen as the body deceleration increased. The delta V also showed same phenomenon.

Figs. 12 and 13 show the amount of toe board, steering shaft intrusion and dummy injury severity.

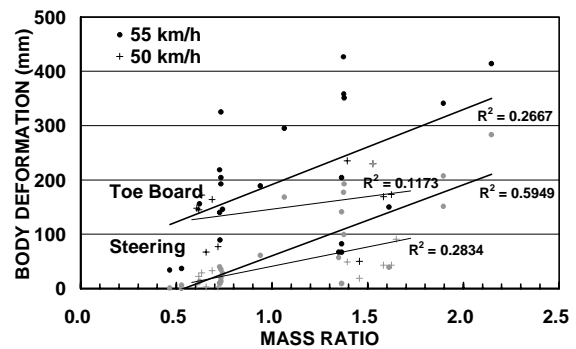


Figure 12. Relationship between Body Deformation and Mass Ratio.

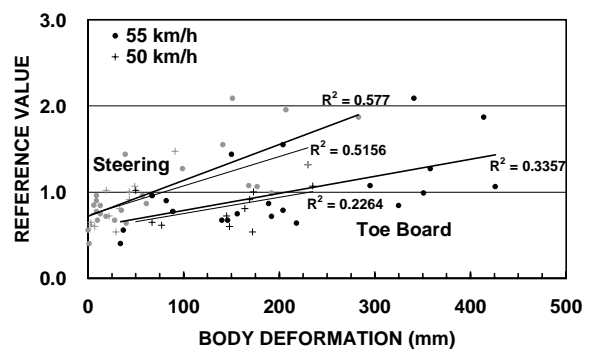


Figure 13. Relationship between Body Deformation and Occupant Injury Severity (Driver Chest G).

The amount of toe board intrusion tended to increase overall as the mass ratio increased.

Likewise, the amount of steering shaft intrusion also tended to increase in accordance with an increase of mass ratio.

It was observed that when the amount of toe board and steering intrusion increase, Chest G which is a major factor in injury severity tended to worsen.

ANALYSIS

The test results clearly show that at the current performance level, the HIC and chest G values exceed the reference value when the crash mass ratio is 1:1.1 or more. (for a crash speed of 55 km/h)








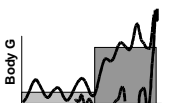
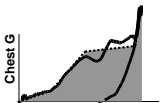
Table 2 shows the Chest G-Displacement characteristics. The factors influencing G-Displacement characteristics are body deceleration, cabin intrusion, and the performance of the occupant restraint system.

The body deceleration characteristics and occupant restraint characteristics in car-to-car crashes were compared for fixed barrier crash test. This method is effective for improving self-protection performance and ODB crash test performance and is suitable for thoroughly evaluating body and restraint system

performance in conditions where the loading input to the body is uneven.

Table 2.

Relationship between Body Deceleration and Deformation and Occupant Injury Severity by Crash Format

Test Procedure	Body Deceleration	Restraint Performance
FULL LAP 		
ODB 		
CTC 		

As previously mentioned, full lap barrier crashes generate the highest average body deceleration, and for this reason, also the largest relative energy absorption by the occupant. On the other hand, ODB crashes exhibit an extremely low deceleration due to the effects of the offset ratio and energy absorption by the honeycomb. As a result, the crash energy translated the occupant was found to be less than that for a full lap crash.

The outcome of a car-to-car crash depends on the characteristics of the two opposing vehicles. Although car-to-car crashes have a low initial deceleration similar to ODB crashes, they also produce extremely high input loads into the cabin and high G levels in the second half of the crash. As a result, the crash energy translated to the occupant by car-to-car offset crash is actually equal to or greater than that for a full lap barrier crash. However, the cabin survival space is significantly reduced compared to the other two tests, and there are many cases where this causes secondary collisions with interior parts which worsen the occupant injury severity.

Thus, avoiding secondary collisions with the vehicle interior through the use of appropriate restraining devices while not increasing body deceleration and maintaining occupant survival space becomes an issue. It is extremely important to achieve a balance between the crash vehicles so that the body deceleration of small lightweight vehicles is not raised to levels higher than is necessary to ensure occupant survival space.

An examination of evaluation test methods that combine these characteristics shows the above-mentioned moving deformable barrier (MDB) crash test to be ideal.

The MDB test method is currently one of the test

method which models car-to-car crashes from the dual perspective of body deceleration characteristics, which control occupant injury severity, and occupant survival space. The proposed car to MDB test method was presented in a previous paper, which presents specifications for preventing MDB over-ride in order to further improve the characteristics of deformable barriers in Figure 14.

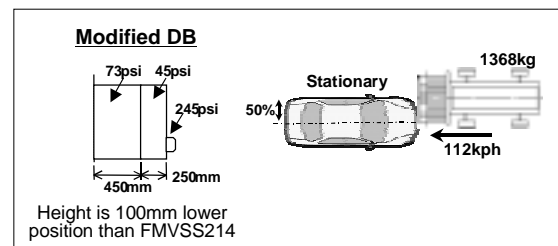


Figure 14. Modified Deformable Barrier and Test configuration.

*See the 16th ESV Paper, Technical Session 1, No. 98-O-08

MDB over-ride is thought to be caused by the interactive forces occurring between the front of the vehicle and the deformable barrier and the inertia characteristics of the vehicle and MDB.

In particular, the over-ride phenomenon is related to the vertical interaction forces between the front of the vehicle and the MDB. A crash between an MDB and car produces less interaction than that which occurs in an actual car-to-car crash. This reduced interaction, which is a result of the inertial characteristics of the deformable barrier, allows greater relative motion between the MDB and car. The deformable barrier and bumper heights were adjusted to avoid this phenomenon, and it was confirmed that over-ride was reduced. Test results show that the body deformation and deceleration of the MDB and the test vehicle closely approximated those in an actual car-to-car crash. The test results also show that although there was significant body deformation to the top of the cabin when MDB over-ride occurred, this did not produce high body decelerations.

Figs. 14 to 16 show body deceleration, deformation and occupant injuries compare with over-ride MDB test result.

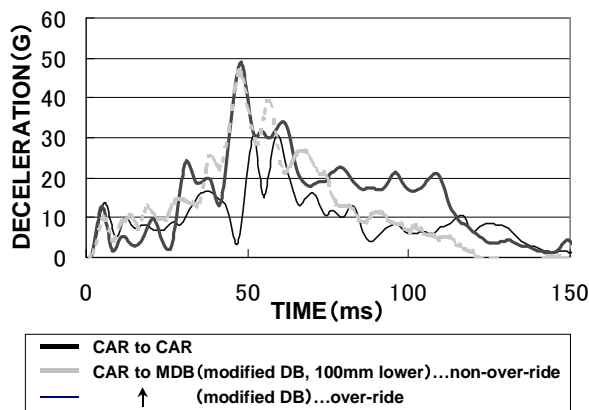


Figure 15. Body Deceleration of Modified MDB and Car-to-Car Test.

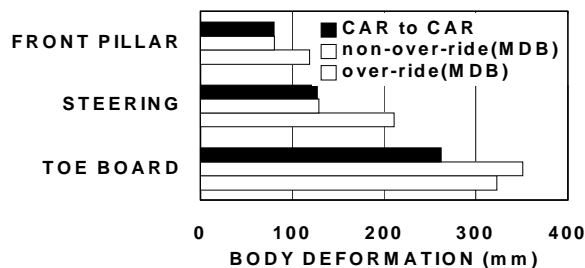


Figure 16. Body Deformation of Modified MDB and Car-to-Car Test.

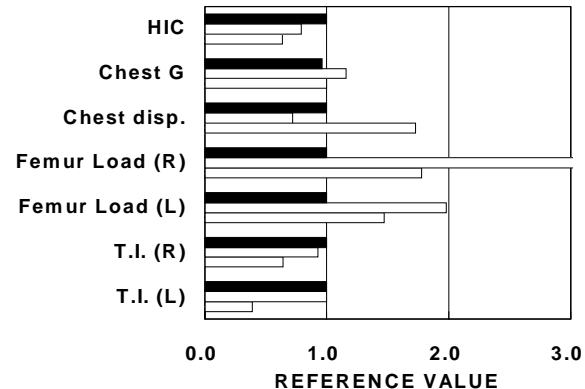


Figure 17. Occupant Injuries of Modified MDB and Car-to-Car Test.

These tests were conducted as research to investigate whether the MDB to car test can be substituted for actual car-to-car crashes between mid-size passenger cars. As a result, it was found that car-to-car crashes may be better reproduced using an MDB to car test as opposed to a conventional fixed barrier test.

It is thought that these MDB characteristics will allow realistic evaluation of compatibility by the MDB test method by using the cumulative average weight of marketed vehicles as the weight and by having the crash angle, that is to say the crash format, conform to market accident formats, etc.

DISCUSSION

When discussing occupant injuries, the concept of body deceleration is thought to be extremely important. In addition, of the three compatibility factors, it is impossible to accurately reflect mass and stiffness to the test method as long as fixed barriers are used.

In order to improve compatibility, it is necessary to establish test methods that can evaluate the various criteria without becoming enmeshed in existing test methods. From the viewpoint of being able to more realistically evaluate the impact input to occupants, the MDB test method is thought to be a suitable method. The proposed MDB tests should be repeated while varying the crash angle, speed, honeycomb characteristics and other factors in consideration of the regional characteristics of each country. Then, these results should be used to investigate and determine vehicle specifications that can improve occupant injury severity and indices for the future evaluation of compatibility.

Finally, the clearest target is to tentatively set characteristic targets for compatible vehicles. Furthermore, it is thought that crash tests with mass ratios that most closely reproduce actual car-to-car crashes are necessary in order to improve incompatibility as quickly as possible.

CONCLUSION

It was confirmed that the test vehicles (up to 2000 year models) used in this research do not achieve compatibility from the viewpoint of occupant injury severity for certain combinations of mass, stiffness and geometry. In particular the influence of steering intrusion and rise caused HIC and Chest G to significantly exceed the reference values, indicating that these are extremely important factors compared to other injury criteria. On the other hand, the tibia index exhibited high values overall, indicating that future analysis such as comparison with ODB tests is necessary to determine whether this is rooted in the body deformation characteristics of car-to-car crashes. Occupant injury is a compound phenomenon caused by body deformation, deceleration and secondary collisions, so the simultaneous improvement of both body countermeasures and restraining devices is thought to be the key to improving compatibility in the future.

The bottoming out and over-ride problems of the MDB test method were improved in this specific test. The resulting body deformation, body deceleration and occupant injury severity of the test vehicles matched closely with actual car-to-car tests. However, as mentioned above this moving deformable barrier (MDB) test method reproduced only crashes between

mid-size passenger cars, and there are plans to also investigate test methods that can evaluate compatibility in terms of aggressivity and self-protection performance while varying the specifications to match real world accidents.

REFERENCES

Hampton C. Gabler, William T. Hollowell “NHTSA’s Vehicle Aggressivity and Compatibility Research Program” Enhanced Safety Vehicle Paper No. 98-S3-O-01, June 1998, Winsor, Ontario CANADA

Christian Steyer, Marc Delhommeau, Pascal Delannoy “Proposal to Improve Compatibility in Head on Collisions” Enhanced Safety Vehicle Paper No. 98-S3-O-05, June 1998, Winsor, Ontario CANADA

Stephen Summers, Alope Prasad, William T. Hollowell “NHTSA’s Vehicle Compatibility Research Program”, Society of Automotive Engineers Paper No. 1999-01-0071. March 1999

M J Edwards, J Happian- Smith, N Byard, H C Davies, and C A Hobbs “Compatibility-the essential requirements for cars in frontal impact”, Vehicle Safety 2000 Paper No. C567/011/2000 June 2000 London, UK

K H Digges and A M Eigan “Load-cell barrier measurements of geometric compatibility”, Vehicle Safety 2000 Paper No. C567/060/2000 June 2000 London, UK

James Holgate “Frontal Offset Test Conditions”, SAE Frontal Offset Crash Testing and Lower Extremity Injuries TOPTECs January 2000.

Koji Mizuno “Current Situation and Problem of Vehicle Compatibility” Japan Society of Automotive Engineers Paper No. 9942628

Tomiji Sugimoto, Yoshiji Kadotani, Shigeru Ohmura “The Offset Crash Test-A Comparative Analysis of Test Methods” Enhanced Safety Vehicle Paper No. 98-S1-O-08, June 1998, Winsor, Ontario CANADA